
The Compton Spectrometer and Imager (COSI)

Exploring nuclear astrophysics of the Milky Way in the MeV band

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The COSI-SMEX Collaboration



UC Berkeley and UC San Diego

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- Bill Craig (Project Manager)
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Goddard Space Flight Center

- T. Brandt, A. Smale, C. Kierans, E. Burns

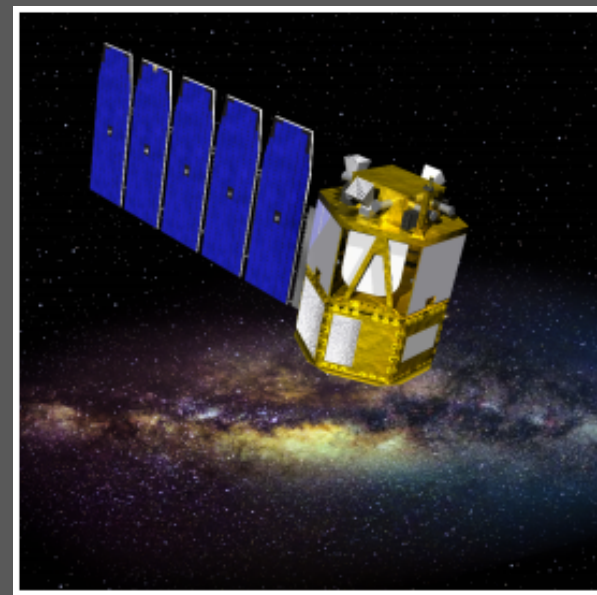
Clemson University

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Northrop Grumman

Collaborators

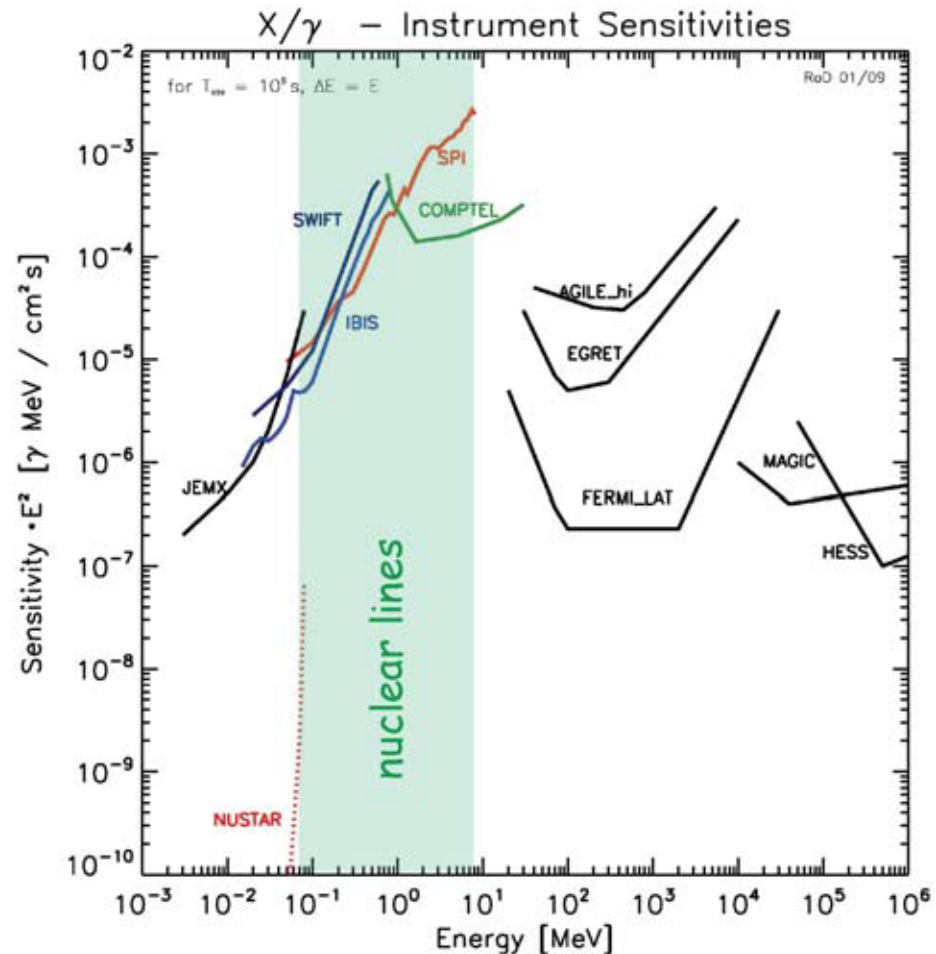
- P. Jean, P. von Ballmoos, J. Malzac, C. Fryer, H. K. Chang, F. Travecchio



Every day, COSI will cover the entire sky, resulting in a sensitive all-sky map in the 0.2-5 MeV range

The MeV Gap

- ❑ Previous missions have had poor sensitivity in the 0.1-20 MeV range
- ❑ Discovery space where there is known to be interesting physics
 - Nuclear line emission
 - 511 keV annihilation line
 - Gamma-ray transients (GRBs, flaring blazars)



Diehl+13

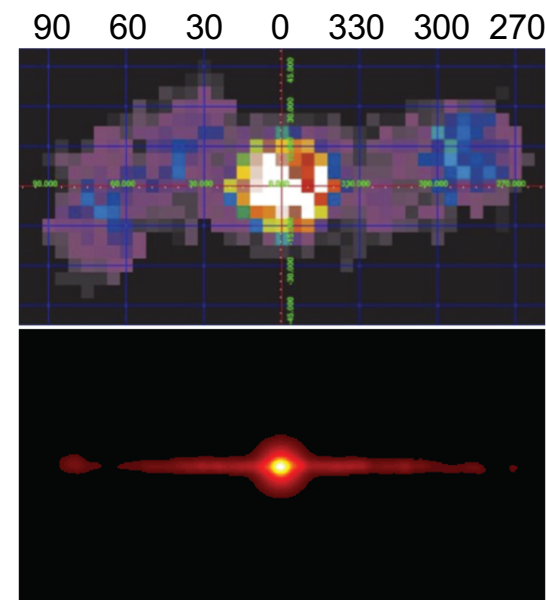
COSI-SMEX Science Objectives

- ☐ Pinpoint the sources of Galactic positrons
- ☐ Reveal sites of element formation
- ☐ Probe the physics in extreme environments with polarimetry
- ☐ Find counterparts to merging neutron stars and high-energy neutrino events

511 keV with
INTEGRAL
(Bouchet+10)

Now

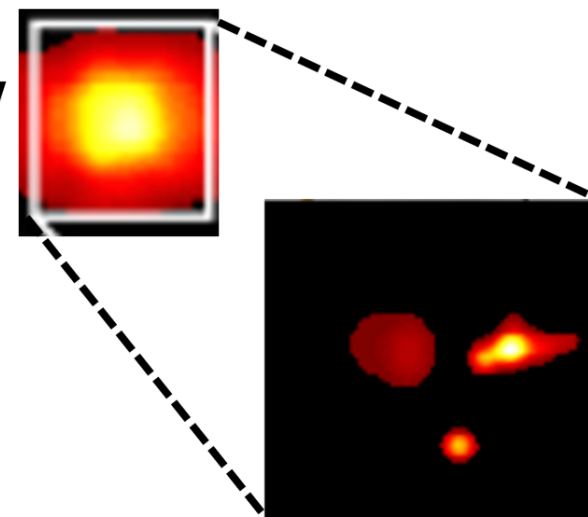
COSI



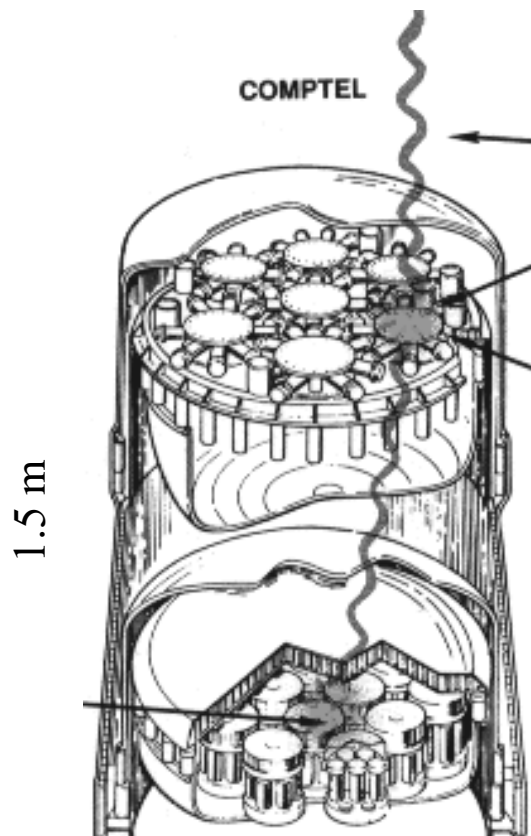
^{26}Al 1809 keV with
COMPTEL

Now

COSI



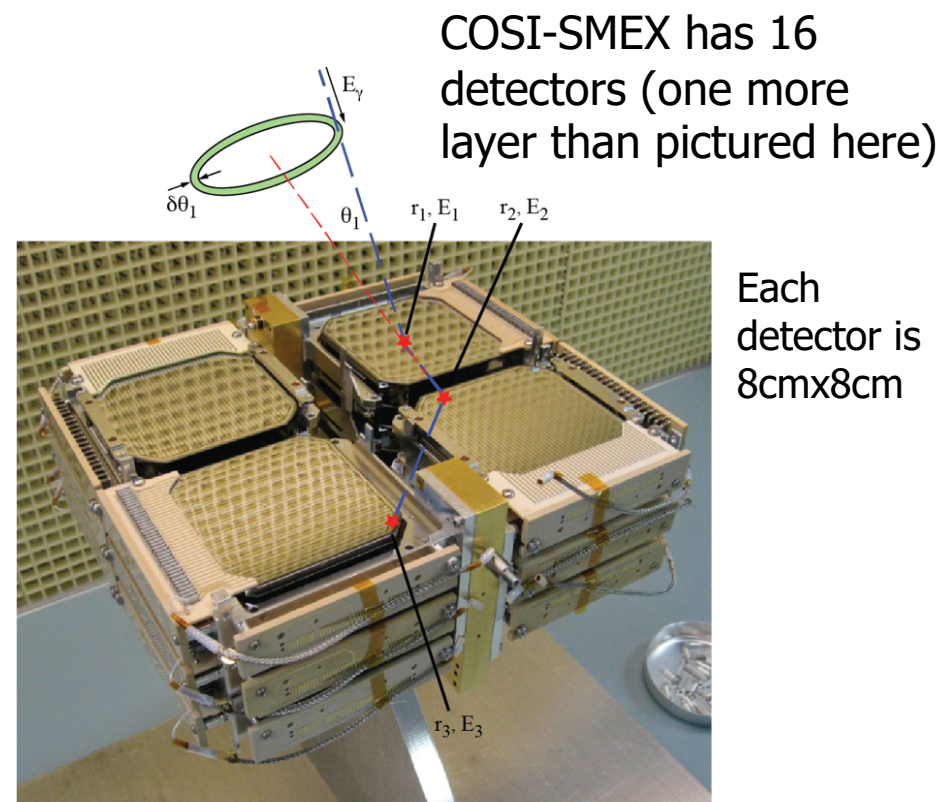
Compton Telescopes: from COMPTEL to COSI



→
30+ years of
development
through NASA
R&D

CGRO/COMPTEL:

- $\sim 40 \text{ cm}^3$ resolution
- $\Delta E/E \sim 10\%$
- up to 0.4% efficiency



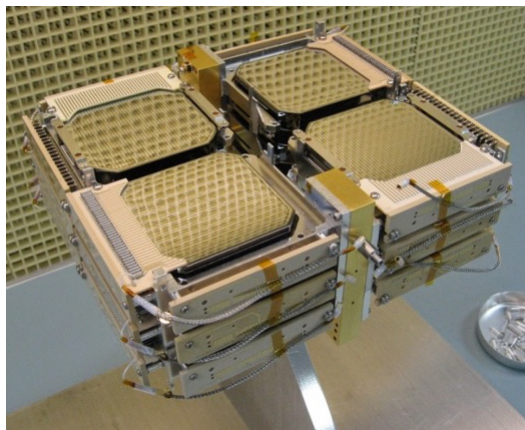
COSI:

- $< 1 \text{ mm}^3$ resolution
- $\Delta E/E \sim 0.2-1\%$
- up to 16% efficiency
- bandpass covers 511 keV
- polarization
- Vastly improved performance with a fraction of the mass and volume

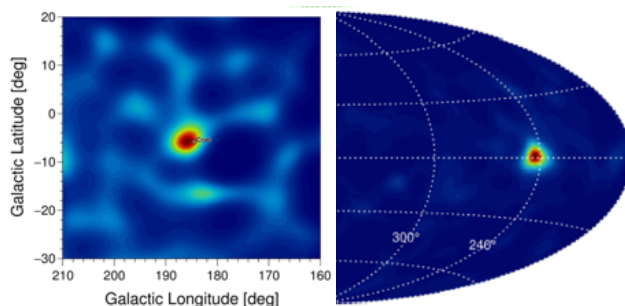
Astrophysics Research and Analysis (APRA) Balloon Program Heritage



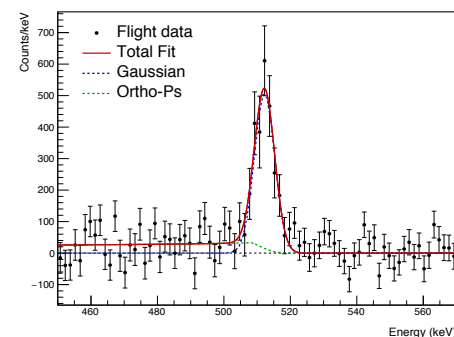
- Proof of concept demonstrated with COSI-APRA
- Successful flights with 2 detectors in 2005 and 10 detectors in 2009
- Instrument with 12 GeDs flew for 46 days in 2016



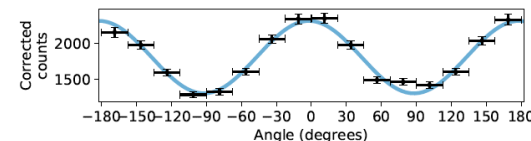
Germanium double-sided strip detectors (GeDs)



- **Imaging** a GRB (Lowell+), the Crab nebula (Sleator+), 511 (Siegert+), and more
- **Real-time GRB reporting**



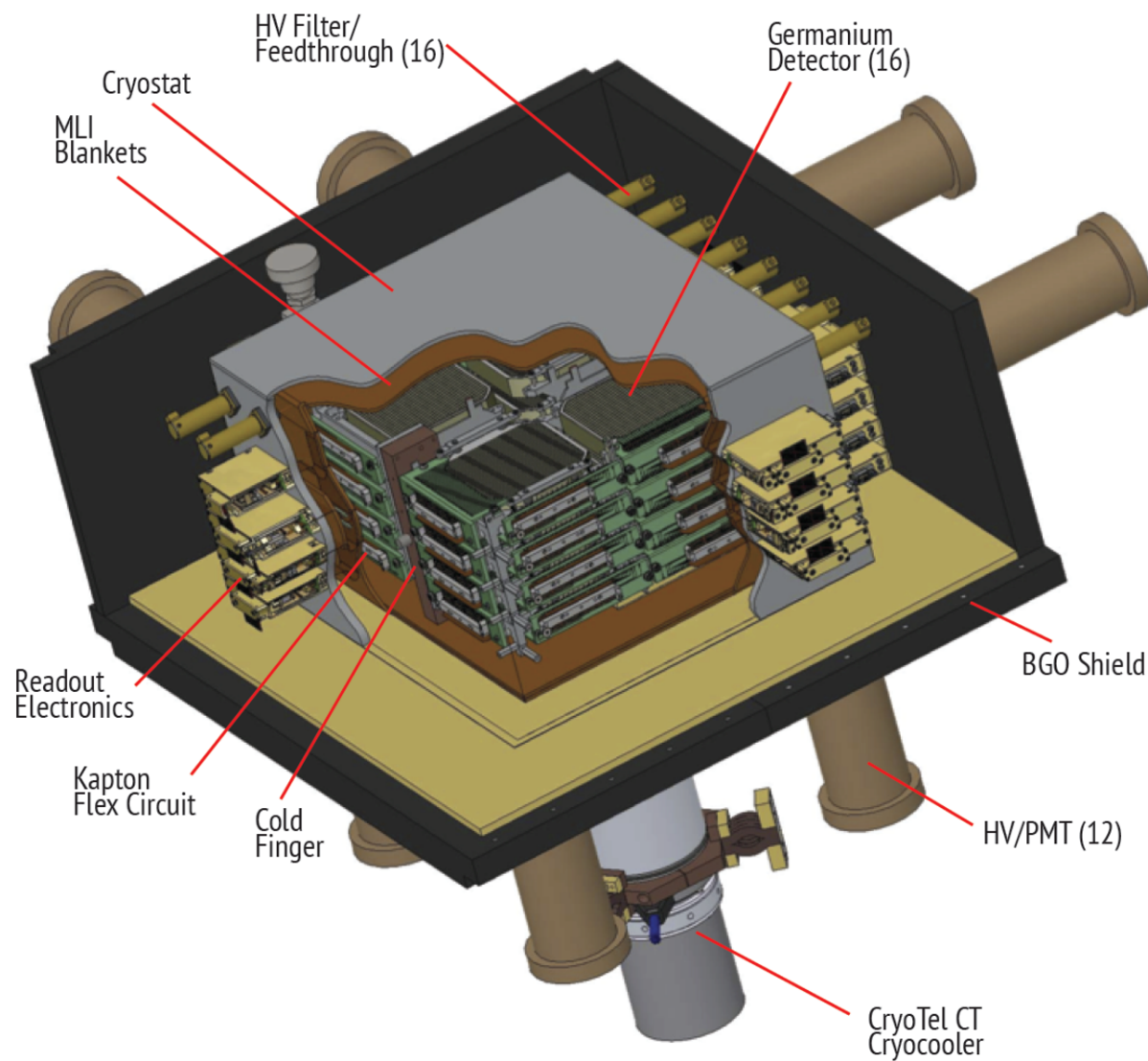
Spectrum
of 511 keV
emission
(Kierans+,
Siegert+)



Polarization measurement
capabilities proven (Lowell+)

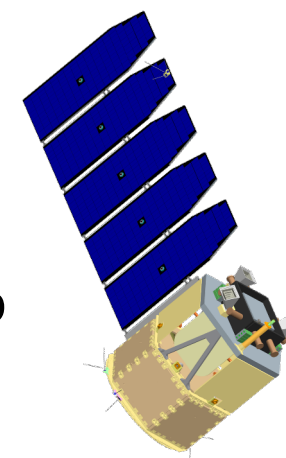
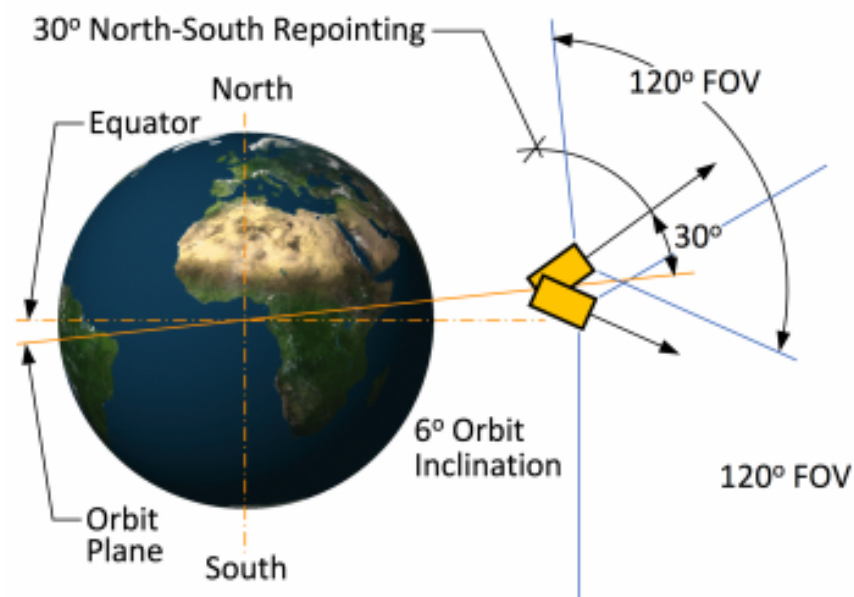
COSI-SMEX Instrument

- ❑ 16 GeDs in vacuum cryostat operating at $<80\text{K}$
- ❑ Active shielding for background rejection
 - Bismuth germanate (BGO) scintillators read out by PMTs



COSI-SMEX Orbit and Operations

- ❑ Near-equatorial orbit to avoid South Atlantic Anomaly to minimize background
- ❑ North-South repointing every 12 hours to cover the whole sky every day
- ❑ Capability for targets of opportunity (TOOs)
 - Expected to be <10% of observing time
- ❑ Rapid transient alerts
 - GRB localizations to <1 deg in <1 hr (<15 min goal)



- Spacecraft: Northrop Grumman LEOStar-2 bus

COSI-SMEX Performance Estimates

Characteristic	Performance	Rationale
Energy Range	0.2-5 MeV	Polarization/511/nuclear lines
Sky Coverage	25% sky FOV 100% per day	All-sky maps; source monitoring; GRBs
Energy Resolution	0.2-1%	511 keV and nuclear line science
Angular Resolution @1809 keV	1.5° (FWHM)	Compare to 3.8° for COMPTEL
Narrow Line Sensitivity (2 years, 3 σ)	[photons cm ⁻² s ⁻¹]	
511 keV	7.9x10 ⁻⁶	Galactic flux $\sim 10^{-3}$ cm ⁻² s ⁻¹ ($\sim 125\times$)
1809 keV	1.7x10 ⁻⁶	Galactic flux $\sim 7\times 10^{-4}$ ($>400\times$)
Flux limit for polarization	15 mCrab	Reaches bright AGN; Galactic black hole transients often >100 mCrab
Fluence limit for GRB polarization (50% MDP)	4x10 ⁻⁶ erg cm ⁻²	Expect COSI to obtain polarization measurements for ~ 40 GRBs in 2 yr

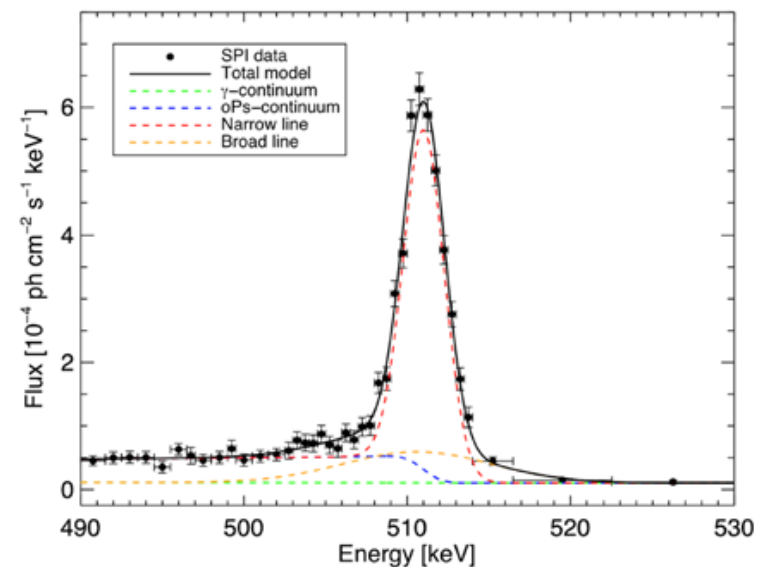
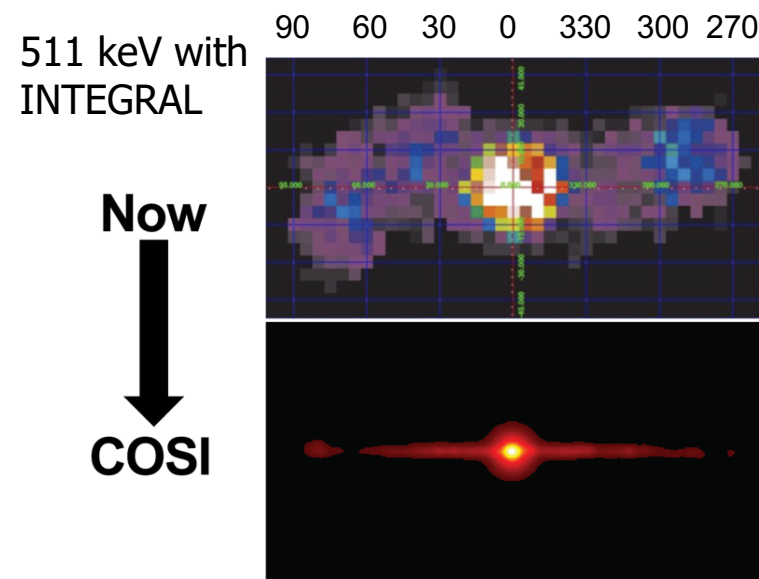
Performance Estimates: Tomsick+19, arXiv:1908.04334, Astro2020 APC White Paper

Galactic flux of 511 keV: E.g., Skinner+15, Siebert+16

Galactic flux of 1809 keV and COMPTEL: Schonfelder+93, Oberlack+96

Galactic Positrons

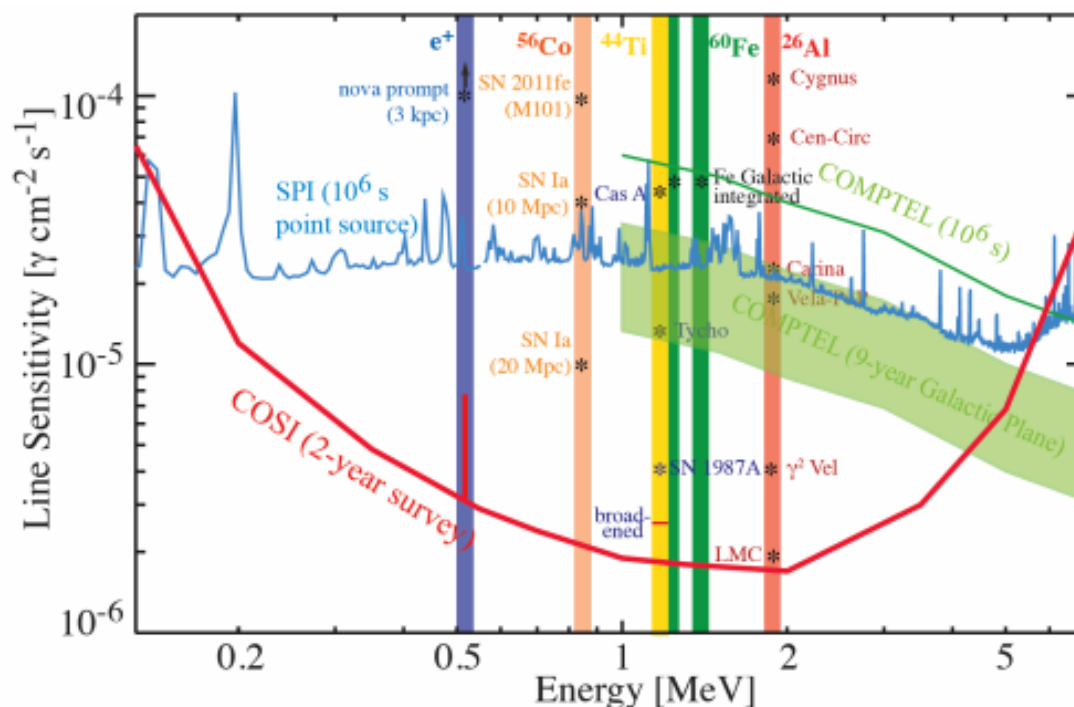
- ❑ Origin of Galactic positrons remains uncertain despite five decades of study
- ❑ INTEGRAL/SPI image shows a bright bulge and a fainter disk
 - ^{26}Al decay is at least a contributor to the disk emission
- ❑ COSI will:
 - Determine if there are point sources or sub-structure
 - Constrain the positron propagation distance by comparing to ^{26}Al distribution
 - Measure the disk scale-height and determine the total Galactic positron production rate



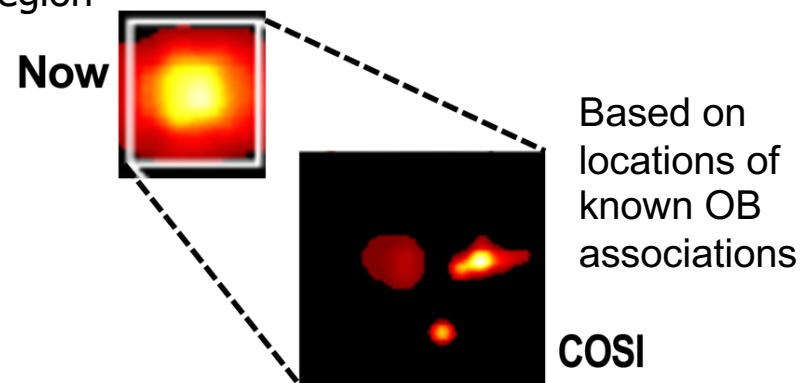
INTEGRAL/SPI: Jean+2006

Revealing Element Formation

- ^{60}Fe (1173, 1333 keV)
 - $t_{1/2} = 2.6$ Myr
 - Only released into the ISM by CCSNe
 - COSI will make the first ^{60}Fe map
- ^{26}Al (1809 keV)
 - $t_{1/2} = 720$ kyr
 - Produced by high-mass stars during their lifetime
 - Higher resolution map compared to COMPTEL
- ^{44}Ti (1157 keV)
 - $t_{1/2} = 60$ yr
 - COSI will survey the Galaxy for young SNe



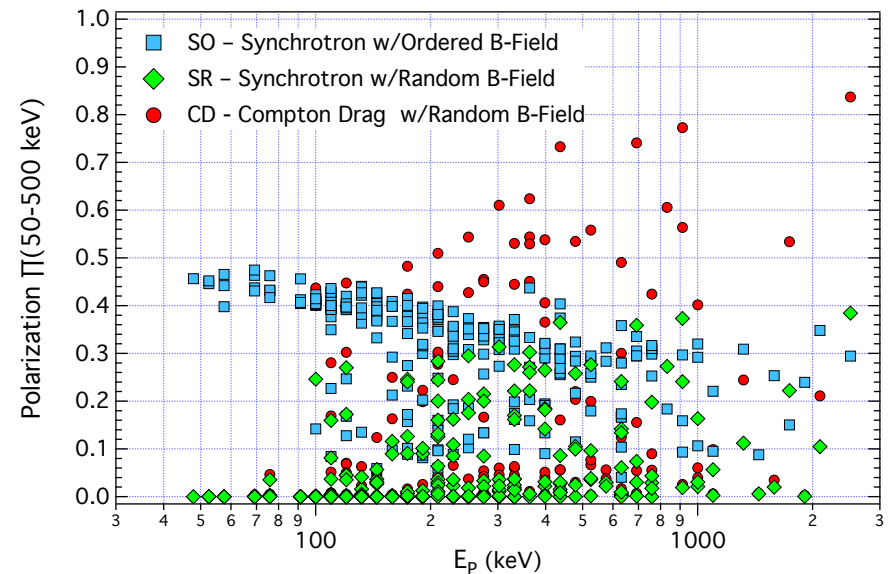
^{26}Al 1809 keV with
COMPTEL for the
Cygnus region



Insight into Extreme Environments with Polarization (GRBs)



- ❑ Polarization measurements provide unique diagnostics for determining emission mechanisms and source geometries
- ❑ Most recent progress on GRB polarization by POLAR mission (Zhang+19)
- ❑ COSI will measure the polarization of ~ 40 GRBs in a 2-year mission
- ❑ \sim a dozen GRBs with polarization measurements to $\pm 5\text{-}10\%$



Toma+09;
McConnell+16

Insight into Extreme Environments with Polarization (Pulsars, AGN, Black Hole Binaries)



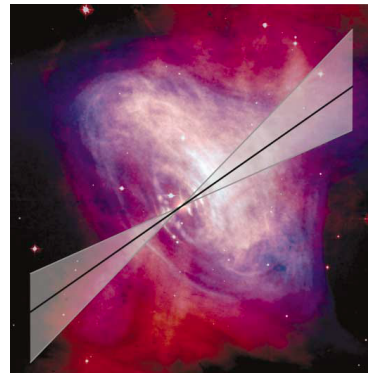
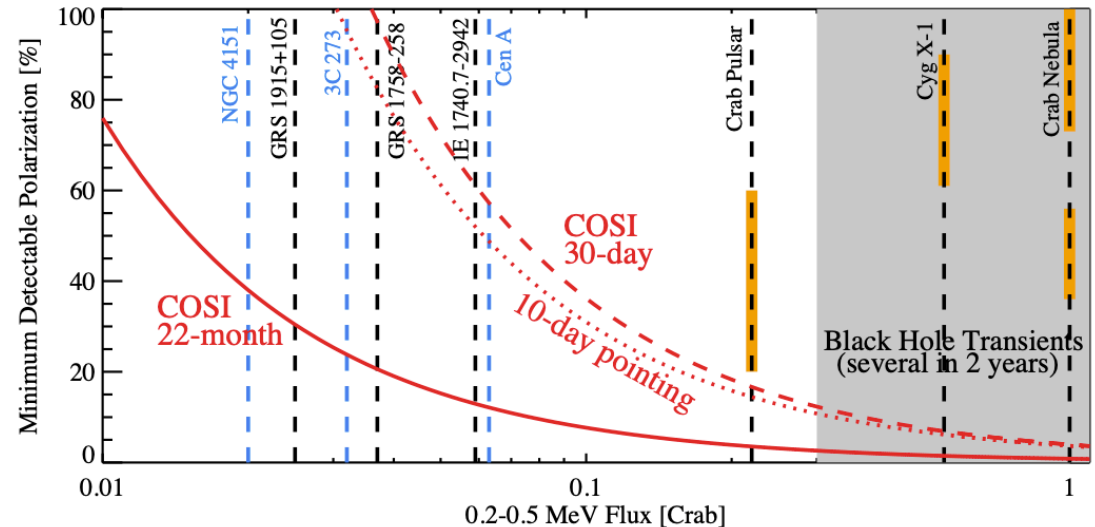
❑ Improve over previous high-energy polarization measurements of the Crab and Cyg X-1

- INTEGRAL (both)
- AstroSat (Crab)
- POGO+ (both, but at lower energy)
- Hitomi/SGD (Crab)

❑ AGN: Cen A, 3C 273, NGC 4151

❑ Black hole binaries

- Several persistent
- Several transient



Crab pulsar and nebula (Dean+08)

AGN (e.g., Cen A)

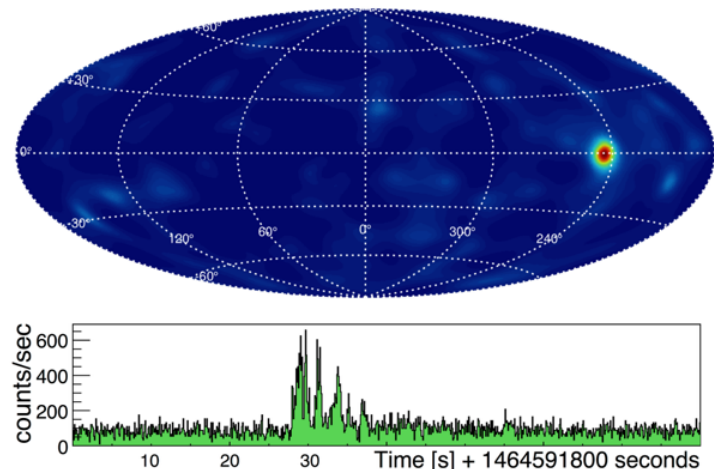
- High polarization (~60%) for Synchrotron Self-Compton from a jet
- Lower polarization for Compton scattering from a hot tenuous accretion disk corona

Multimessenger Astrophysics

- ❑ COSI contributes to MMA with its capability to detect and localize counterparts
 - Short GRBs from merging binary neutron stars (15-20 in 2 yrs)
 - Gamma-ray search for counterparts to high-energy neutrinos

- ❑ Compton telescopes combine large FOV with good localization capabilities
 - Covers a different part of the parameter space than coded aperture masks or scintillators

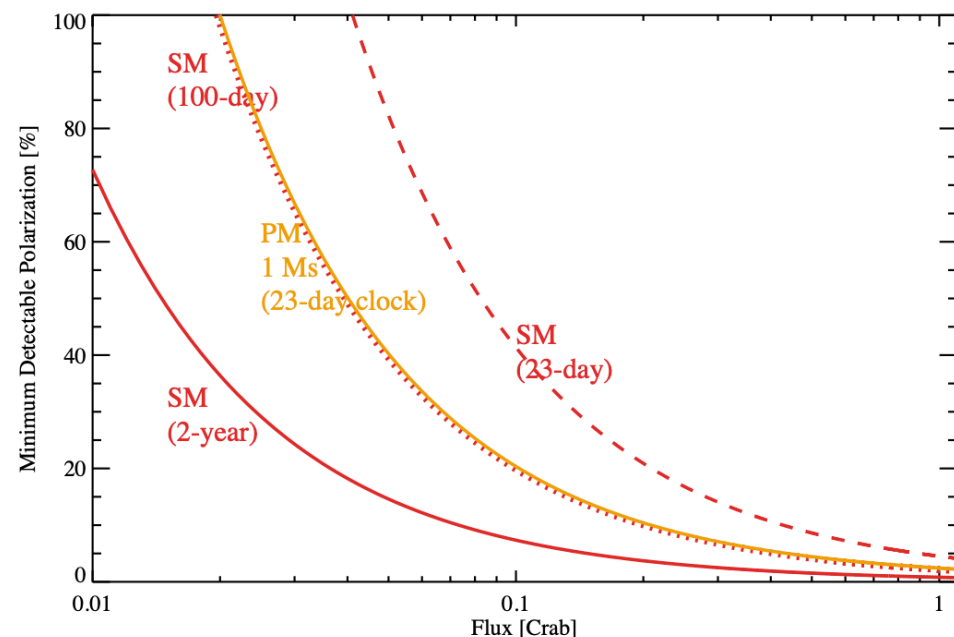
- ❑ COSI's BGO shields
 - ~double the field of view
 - Allow arrival time comparison with GW signal



GRB 160530A: real-time reporting by COSI in 2016 (GCN#19473)

Examples of Potential TOO's

- ❑ Very likely to occur in the 2-year prime mission
 - Several bright transient black hole binaries
- ❑ Likely to occur
 - High-energy neutrino events
- ❑ Lower probability but large payoff
 - ***Nearby core collapse supernova***
 - ***Nearby binary neutron star merger***
 - Type Ia SNe within 10-20 Mpc
 - Classical novae



Polarization sensitivities for Survey Mode (SM) vs. Pointed Mode (PM)

- Sensitivities can be reached ~4x faster in PM

It is important to have a gamma-ray spectrometer ready when these things happen.

Science Enhancement Options

☐ Current options

- Guest investigator program like Fermi's
 - Specific analysis projects
 - Development of specialized software
 - Target of opportunity proposals
- Solar studies
- Improved telemetry for faster reporting of gamma-ray transients

☐ Open to suggestions

Astro2020 APC White Paper for Additional Information

❑ arXiv:1908.04334

❑ Activity, Project,
and Statement of
the Profession
Consideration
White Paper

❑ APC WP discusses
how COSI-SMEX
addresses science
in 15 of the
Astro2020 Science
White Papers

Astro2020 APC White Paper

The Compton Spectrometer and Imager

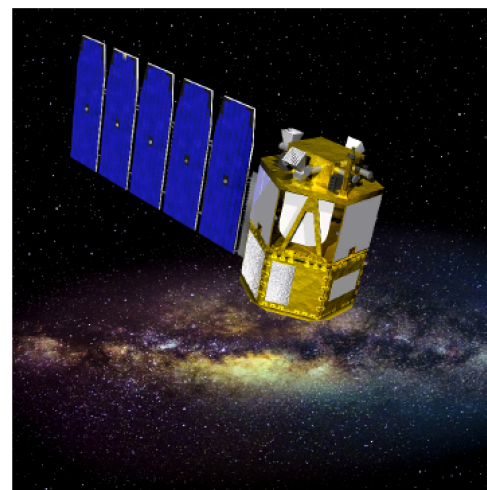
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Summary and Conclusions

- ❑ COSI-SMEX will cover the full sky in a bandpass that has not yet been explored to its full discovery potential
- ❑ The combination of large FOV, excellent energy resolution, and imaging is powerful for studying the 511 keV line and nuclear lines from the Galaxy
- ❑ The addition of polarization sensitivity opens a new window on extreme environments
- ❑ COSI-APRA has provided an excellent opportunity to develop the required hardware and software (MEGALib, Zoglauer+06)

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